Journal of Cardiology 67 (2016) 115–121

Contents lists available at ScienceDirect

Journal of Cardiology

journal homepage: www.elsevier.com/locate/jjcc

Original article

Pre-procedural evaluation of the left atrial anatomy in patients referred for catheter ablation of atrial fibrillation

Yoshihisa Kanaji (MD), Shinsuke Miyazaki (MD)*, Jin Iwasawa (MD), Noboru Ichihara (MD), Takamitsu Takagi (MD), Akio Kuroi (MD), Hiroaki Nakamura (MD), Hiroshi Taniguchi (MD), Hitoshi Hachiya (MD), Yoshito Iesaka (MD)

Cardiovascular Center, Tsuchiura Kyodo Hospital, Tsuchiura, Ibaraki, Japan

ARTICLE INFO

Article history:
Received 9 February 2015
Received in revised form 22 February 2015
Accepted 27 February 2015
Available online 3 April 2015

Keywords:
Computed tomography
Anatomical variant
Atrial fibrillation
Catheter ablation

ABSTRACT

Background: Cardiac computed tomography (CT) provides accurate imaging of the pulmonary vein (PV) and left atrial (LA) anatomy. This study aimed to evaluate the prevalence and morphological characteristics of anatomical variants that could influence atrial fibrillation (AF) ablation procedures.
Methods and results: One thousand forty consecutive patients (62 ± 10 years, 243 female, 644 paroxysmal AF) undergoing pre-procedural imaging with a 320-row CT and their first AF ablation procedure were analyzed. A total of 194 (18.7%) patients had anatomical variants. Left, right, and inferior common PVs were observed in 118, 5, and 6 patients, respectively. Three right and left PVs were observed in 44 and 4 patients, respectively. Three patients had remnants of PVs after lobectomies, and significant PV stenosis was observed in one. Supernumerary PVs that drained into the LA and diverticula were observed in eight patients. One patient had a string-like structure connecting the LA septum and posterior LA, and the others had membranous structures incompletely compartmentalizing the LA. Three patients had persistent left superior vena cavae, two strong deviations of the LA and PVs, and one dexiocardia. All patients underwent successful PV isolation during the index procedure.
Conclusions: Patients referred for AF ablation often have anatomical variants, which could influence the procedure. This information might aid in planning procedural strategies, and reducing unexpected procedural complications in AF ablation.

Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia, and catheter ablation is recognized as a reasonable therapeutic option for the treatment. Confirmed electrical disconnection of the left atrium (LA) from the pulmonary veins (PVs) is the cornerstone of the catheter ablation of paroxysmal AF, and is an important component of more extensive ablation procedures for persistent AF [1–3]. The integration of three-dimensional electroanatomical mapping systems with pre-acquired images of the cardiac anatomy is a recent major advancement in AF ablation. Prior studies have shown that cardiac computed tomography (CT) provides an accurate imaging of the PV and LA anatomy with excellent spatial resolution, supplying the necessary anatomic information for a successful ablation. The objective of this study was to evaluate the prevalence and morphological characteristics of clinically important anatomical variants that could influence the AF ablation procedure using pre-procedural cardiac CT in a large population referred for catheter ablation of AF.

Methods

Study population

This study consisted of 1040 consecutive patients who underwent cardiac multidetector CT (MDCT) prior to their first catheter ablation of AF at our institute between October 2010 and December 2014. All patients underwent a PV antrum isolation (PVAI) in the index procedure, and the ablation lines were placed around the ostia of the ipsilateral PVs. AF was classified according to the HRS/EHRA/ECAS 2012 Consensus Statement on Catheter and Surgical Ablation of AF [3]. All patients gave their written informed consent for participation in the study.

* Corresponding author at: Cardiology Division, Cardiovascular Center, Tsuchiura Kyodo Hospital, 11-7 Manabeshin-machi, Tsuchiura, Ibaraki 300-0053, Japan. Tel.: +81 29 823 3111; fax: +81 29 826 2411.
E-mail address: mshinsuke@k3.dion.ne.jp (S. Miyazaki).

http://dx.doi.org/10.1016/j.jjcc.2015.02.016
0914-5087/

CT scanning

Gated contrast-enhanced CT of the chest was performed with a 320-row MDCT scanner (Aquilion one, Toshiba, Otawara, Japan). A bolus of 70–100 ml of iodinated contrast media was injected intravenously at an injection rate of 3.0–4.5 ml/s using an automatic injector to regulate the iodine injection speed as 22.2 mgI/kg/s. Scanning was initiated with a 10-second delay after the signal density level reached a predefined threshold of 200 Hounsfield units in the LA. The following parameters were used for scanning: electrocardiogram-gated acquisitions, 120 kVp, 110–206 mAs, and 320 × 0.5-mm slice collimation. Scans were performed from the tracheal bifurcation to the diaphragm. Reconstructions were performed with a FC13 to generate 0.5-mm-thick slices with a reconstruction interval of 0.5 mm with a workstation (SYNAPSE VINCENT, Fujifilm, Tokyo, Japan). All images were acquired in the supine position and reviewed independently by an experienced radiologist and cardiologist.

Mapping and ablation protocol

The ablation was performed according to the strategy described previously [4–7]. In brief, after a single transseptal puncture, two long sheaths (SL0, St. Jude Medical, Minneapolis, MN, USA) were introduced into both superior PVs. Pulmonary venography during ventricular pacing and contrast esophagography were performed to obtain the relative locations of the PV ostia vis-a-vis the esophagus. Two circular mapping catheters (Lasso, Biosense Webster, Diamond Bar, CA, USA) were placed in the superior and inferior PVs, and the left-sided, then right-sided, ipsilateral PVs were circumferentially and extensively ablated guided by a 3-D mapping system (CARTO3, Biosense Webster). The endpoint was the achievement of bidirectional conduction block between the LA and PVs. Radiofrequency current was delivered point-by-point with a 3.5 mm externally irrigated-tip quadripolar ablation catheter (Thermocool, Biosense Webster) with a power of up to 35 W, target temperature of $\leq$38 °C, and irrigation rate of 30 ml/min. The power was limited to 20 W on the posterior wall close to the esophagus. In patients with non-paroxysmal AF, a substrate modification, when AF persisted after the PVAI, was performed sequentially to eliminate any complex fractionated atrial electrograms in both atria [5,6].

Results

In total, 1040 patients (62 ± 10 years, 243 female, 644 paroxysmal AF) underwent cardiac MDCT prior to the first AF ablation procedure. The mean LA diameter was 41.6 ± 6.2 mm, and the left ventricular ejection fraction was 64.1 ± 8.8%. Among the 1040 patients, 846 (81.3%) patients had a normal LA and PV anatomy, whereas the remaining 194 (18.7%) patients had some anatomical variant, which could influence the AF ablation procedure.

The most common anatomical variant was a common PV. Left (Fig. 1A, B), right (Fig. 1C, D), and inferior common PVs (Fig. 2) were observed in 118 (11.3%), 5 (0.48%), and 6 (0.58%) patients, respectively. Three left PVs (Fig. 3A, B) and three right PVs (Fig. 3C, D) were observed in 4 (0.38%) and 44 (4.2%) patients. Three (0.29%) patients had remnants of PVs (Fig. 4A–C) after a lobectomy for lung cancer. In one (0.1%) patient, significant PV stenosis was observed in the LIPV despite no history of any previous procedure (Fig. 4D). In all cases except in the cases with inferior common PVs, an ipsilateral PV isolation was successfully achieved. In the patients with inferior common PVs, the PV was isolated segmentally.

Supernumerary PVs that drained into the LA and diverticula were observed in eight (0.77%) patients (Fig. 5). One patient had a string-like structure connecting the LA septum and posterior LA (Fig. 6). One patient had a membranous structure extending from the interatrial septum to the lateral LA like cor triatriatum sinister (Fig. 7). That membranous structure incompletely compartmentalized the LA. In both cases, transseptal LA catheterization into the posterior part of those structures enabled the achievement of a successful PVAI.

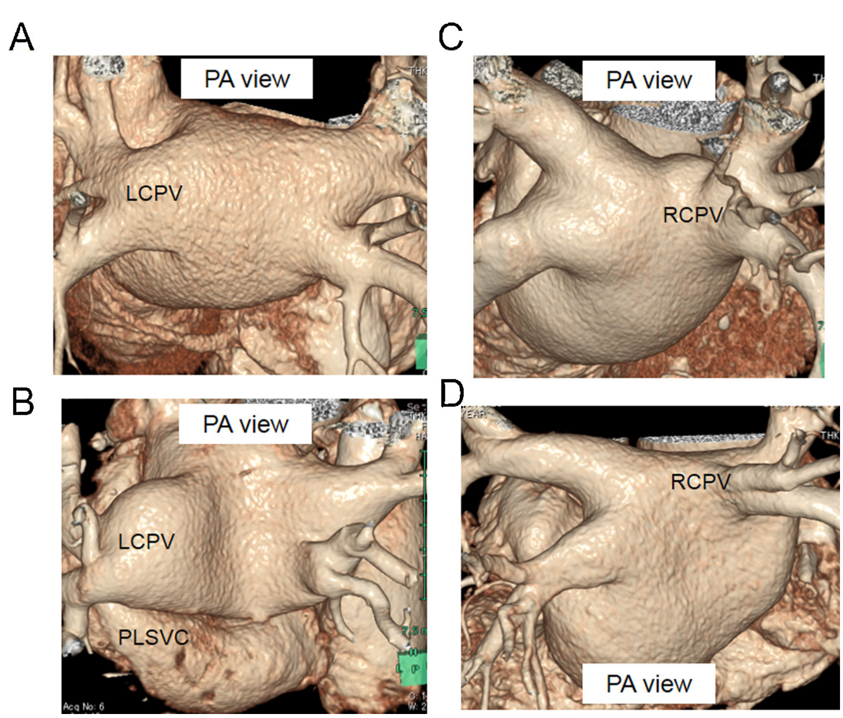

Fig. 1. Left common pulmonary vein (A, B), right common pulmonary vein (C, D), and a PLSVC (B). LCPV, left common pulmonary vein; RCPV, right common pulmonary vein; PLSVC, persistent left superior vena cava; PA, posteroanterior.

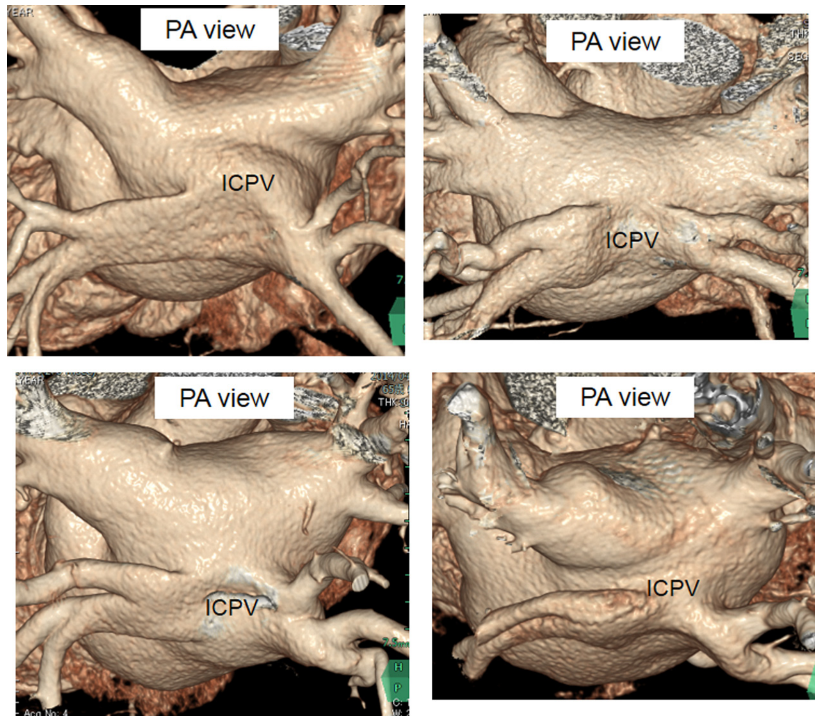

Fig. 2. Various types of inferior common pulmonary veins. ICPV, inferior common pulmonary vein; PA, posteroanterior.

Three (0.29%) patients had a persistent left superior vena cava (Fig. 1B). Two patients (0.19%) had a strong deviation of the LA and PVs (Fig. 4E). One (0.1%) patient had dexiocardia, whereas no other coexistent anomaly was identified. Finally, a successful PVAI was achieved in all patients during the index procedure. A cardiac tamponade, phrenic nerve injury, periesophageal vagal nerve injury, cerebral infarction/transient ischemic attack, pneumothorax, and congestive heart failure occurred in 10, 13, 15, 3, 4, and 4 patients, respectively.

Discussion

Major findings

We evaluated the cardiac structures in a consecutive large series of patients referred for AF ablation. Pre-procedural cardiac MDCT identified anatomical variants, which could influence the ablation procedure, in 18.7% of this population. The most common anatomical variant was a common PV.

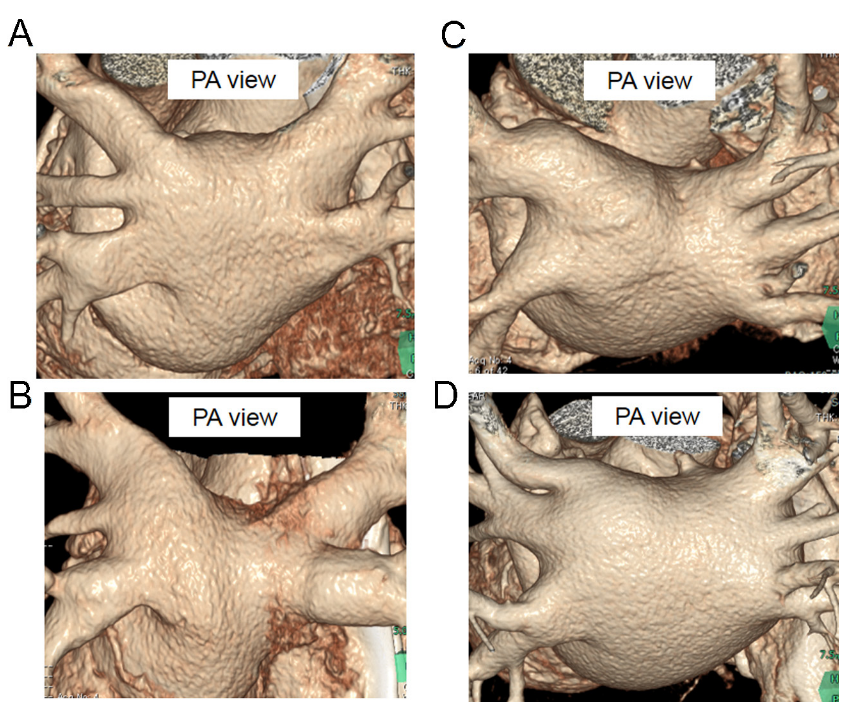

Fig. 3. Three left pulmonary veins (A, B, D) and three right pulmonary veins (C, D). PA, posteroanterior.

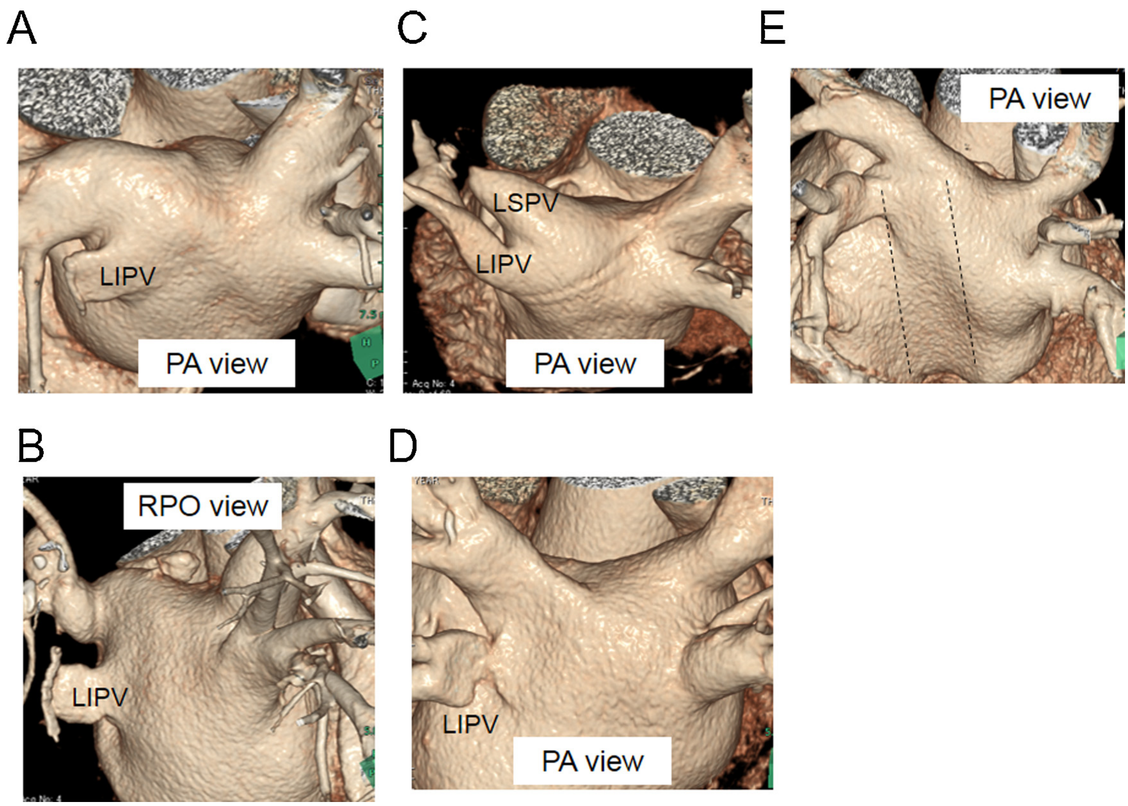

Fig. 4. Remnant of a pulmonary vein after a lobectomy (A–C). Stenosis in the LIPV (D), and a strong deviation of the left atrium and pulmonary vein (E). The dotted lines indicate the dimple by the vertebra. LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; RPO, right posterior oblique; PA, posteroanterior.

AF ablation and cardiac anatomy

Since PV stenosis was recognized as an important complication of AF ablation, the PVAI has become the cornerstone of the AF ablation procedure [3]. Initially, conventional angiography was used to assess the PV and LA anatomy prior to the procedure, however, a complex anatomy could not be deciphered as thoroughly as with CT imaging, and there are significant limitations to using either for real-time navigation assistance. In addition, recent advancements in the technology have enabled the use of a balloon technology for PV isolation. The pre-procedural evaluation of the PV anatomy is essential for considering the indication of such a technology and planning the ablation strategy in individual patients. Previously, Kato et al. elegantly showed the utility of MRI to evaluate the PV anatomy in 28 patients undergoing AF ablation [8]. MDCT is now widely distributed and has an excellent spatial resolution. That

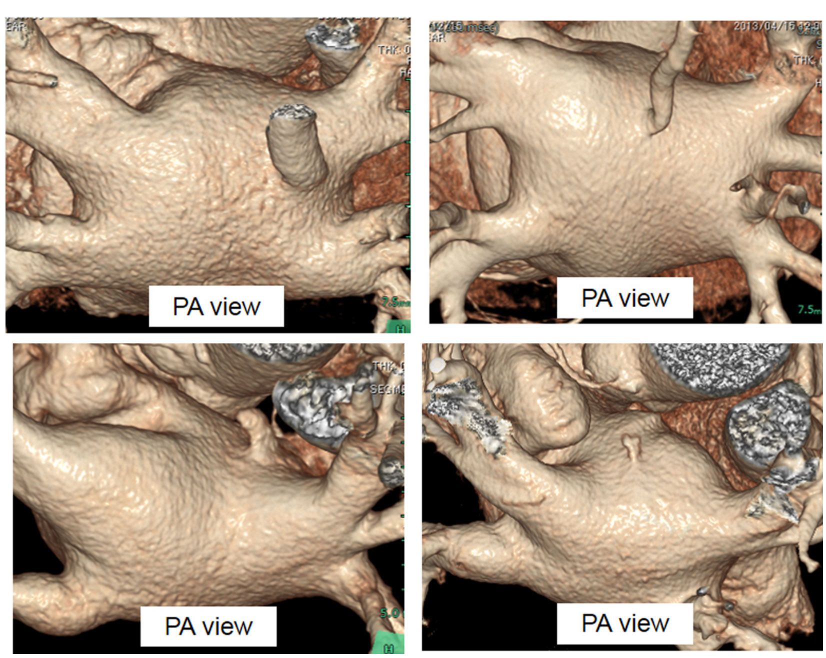

Fig. 5. Various types of supernumerary pulmonary veins and diverticula. PA, posteroanterior.

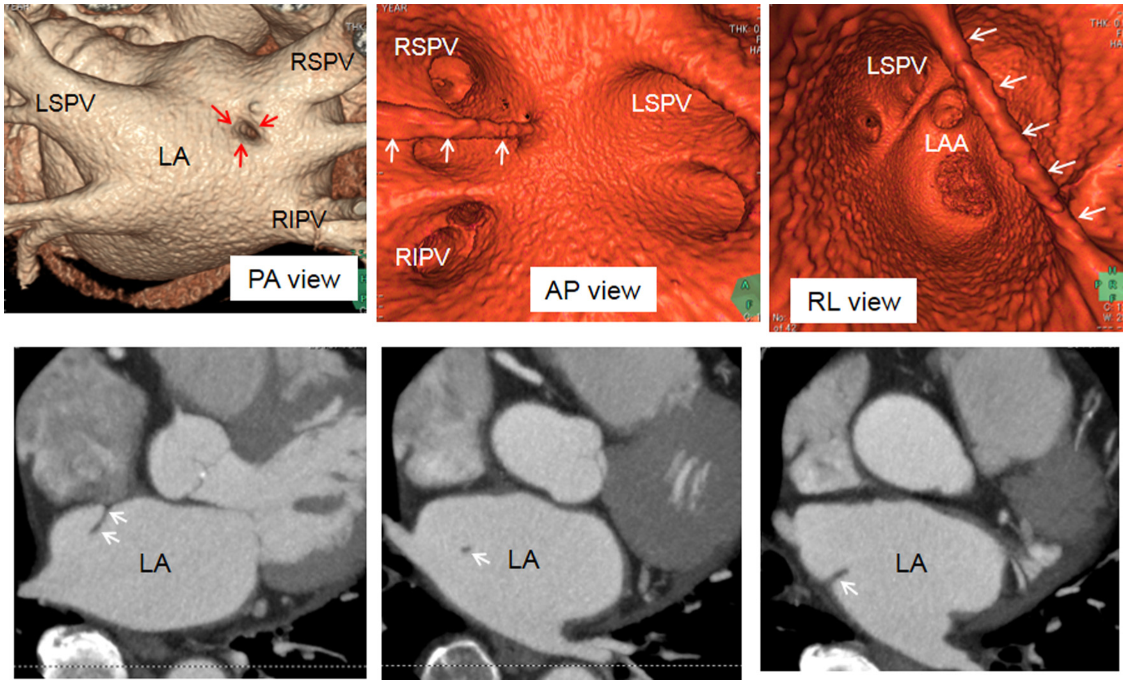

Fig. 6. A string-like structure (white arrows) connects the LA septum and posterior LA. A dimple (red arrows) is observed on the surface. LA, left atrium; LSPV, left superior pulmonary vein; RSPV; right superior pulmonary vein; RIPV, right inferior pulmonary vein; LAA, left atrial appendage; RL, right–left; AP, anteroposterior; PA, posteroanterior. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

information is helpful to decide the circumferential ablation line around the PVs in the radiofrequency ablation pre-procedurally, and is particularly helpful in selecting the PV branches for a successful occlusion while using the balloon technology. In the absence of pre-procedural imaging, the lack of recognizing anatomical variants can result in a greater total amount of contrast media and the radiation time, in addition to a less effective use of the electrical anatomical mapping system.

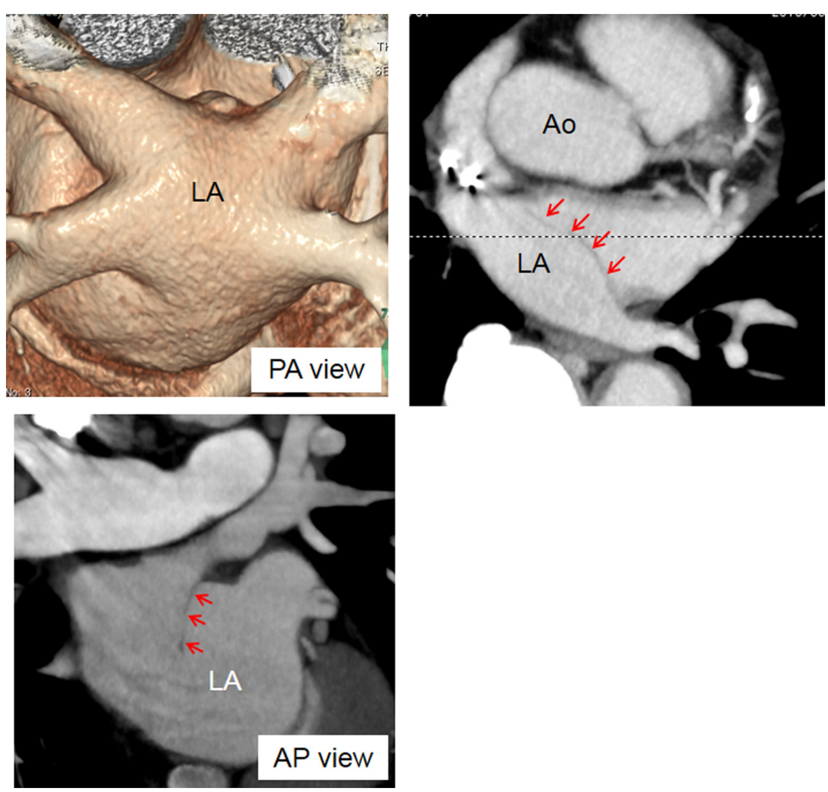

Fig. 7. A membranous structure (red arrows) extends from the interatrial septum to the lateral LA and incompletely compartmentalizes the LA. This structure is not visible on the surface. LA, left atrium; Ao, aorta; AP, anteroposterior; PA, posteroanterior. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

We have demonstrated that the PV anatomy was highly variable due to the presence of additional veins and the common insertion of the PVs. Although an inferior common PV was a rare variant, as Yamane et al. elegantly demonstrated [9], the recognition is critical for a successful PV isolation. A conventional anatomy consisting of a superior and inferior vein on each side occurred in approximately 80% of the population, which was in line with a prior report [8]. In three cases post-lobectomy for lung cancer, a remnant of the PV was observed. The knowledge of the location and length of the remnant PV is critical for deciding if a mapping catheter could be placed inside the PV. A persistent left superior vena cava was identified in three cases. The recognition of this structure is important considering the high arrhythmogenicity. Careful mapping to identify the arrhythmogenicity of any anatomical variant should be considered because any anatomical variant could be arrhythmogenic.

In some patients, there was a supernumerary vein that had an aberrant insertion, with a perpendicular position in relation to the LA. This information usually cannot be obtained by echocardiography or selective angiography. If a catheter is placed inside one of these vessels, it seems likely that a low flow could potentially facilitate excessive heating with a low power and a risk of steam pops or coagulum formation. It potentially could be associated with catheter entrapment, which leads to complications in the catheter ablation of AF. Advanced knowledge of the PV variants maximizes the safety and efficacy of the procedure. No patient had a catheter lodged in these vessels in our series, presumably because of the recognition of the specific anatomy before the procedure.

One patient had a membranous structure extending from the interatrial septum to the lateral LA. This structure incompletely compartmentalized the LA like cor triatriatum sinister. One patient had a string-like structure extending from the LA septum to the posterior LA. In both cases, advanced knowledge enabled a transseptal LA catheterization into the posterior part of those structures, which resulted in a successful PVAI. In the present series, dexiocardia was observed in one case. Cardiac imaging prior to the procedure is mandatory to evaluate the precise anatomic information and coexistence of an anatomical abnormality in such a case. Demonstration of a complex LA and PV anatomy enables the operator to perform a specific catheter selection and approach to the ablation. This pre-procedural knowledge may reduce not only the overall radiation dose and procedure time, but also any unexpected complications during the AF ablation procedure.

In the present study, 320-row MDCT was used. High-speed and wide-coverage MDCT scanners have the advantage of decreased cardiac motion and artifact, and improve the image quality. This provides full cardiac coverage enabling whole heart images without helical scanning. This new technology can significantly reduce the radiation dose more than a typical MDCT scan.

PV/LA anatomy and clinical outcome

Several previous studies investigated the association between the PV/LA anatomy and clinical outcome. Hof et al. demonstrated that the PV anomaly was not associated with the clinical outcome [10]. McLellan et al. reported that an abnormal anatomy (left common PV or accessory PV) and shorter left intervenous ridge length were associated with an increase in the freedom from AF [11]. Sohns et al. showed that AF recurrence was significantly higher in patients with a non-regular PV anatomy [12]. den Uijl et al. showed that an enlargement of the anteroposterior LA diameter and the presence of a normal anatomy of the right PVs are independent risk factors for AF recurrence [13]. These results are neither constant nor universal results. On the other hand, many studies showed that the LA size was an important predictor of AF recurrence, and that the LA volume assessed by CT was a better predictor than the LA diameter measured on echocardiography [10,14,15]. This is not surprising because multiple factors could be associated with AF recurrence, whereas the LA size is an established factor reflecting the degree of anatomical atrial remodeling. Pre-procedural measurement of the LA volume would be helpful for predicting the clinical outcome and selecting candidates for AF ablation.

Clinical implications

Although the cardiac structure is normal in the majority of the patients referred for AF ablation, anatomical variants, which potentially influence the ablation procedure, are often observed in this population. The potential benefits of obtaining a pre-procedural cardiac CT include the ability to quantitatively evaluate the anatomical variants of the LA and PVs. This information is useful in selecting the ablation technology, ablation strategy, and appropriate mapping and ablation catheters.

Study limitations

The study was a single center observational study. The MDCT was not performed in patients with renal failure and allergies to contrast medium. Although the MDCT provided the anatomical information prior to the procedure, the contribution of the MDCT to the decrease in complications was not proven in the present data. The information obtained from cardiac CT was not merged into the 3-D mapping system in the present study.

Conclusion

Patients referred for AF ablation often have anatomical variants, which could influence the procedure. Cardiac imaging using MDCT could precisely identify the anatomical variants pre-procedurally, which might aid in planning the procedural strategy, reducing the procedural complications, and maximizing the efficacy of the AF ablation.

Funding

None.

Disclosures

None.

Acknowledgment

We thank Mr John Martin for the linguistic assistance in the preparation of this manuscript.

References

[1] Haïssaguerre M, Jaïs P, Shah DC, Takahashi A, Hocini M, Quiniou G, Garrigue S, Le Mouroux A, Le Métayer P, Clémenty J. Spontaneous initiation of atrial fibrillation by ectopic beats originating from the pulmonary veins. N Engl J Med 1998;339:659–66.

[2] Takahashi A, Iesaka Y, Takahashi Y, Takahashi R, Kobayashi K, Takagi K, Kuboyama O, Nishimori T, Takei H, Amemiya H, Fujiwara H, Hiraoka M. Electrical connections between pulmonary veins: implication for ostial ablation of pulmonary veins in patients with paroxysmal atrial fibrillation. Circulation 2002;105:2998–3003.

[3] Calkins H, Kuck KH, Cappato R, Brugada J, Camm AJ, Chen SA, Crijns HJ, Damiano Jr RJ, Davies DW, DiMarco J, Edgerton J, Ellenbogen K, Ezekowitz MD, Haines DE, Haissaguerre M, et al. 2012 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design. Heart Rhythm 2012;9:632–96.

[4] Uchiyama T, Miyazaki S, Taniguchi H, Komatsu Y, Kusa S, Nakamura H, Hachiya H, Iesaka Y. Six-year follow-up of catheter ablation in paroxysmal atrial fibrillation. Circ J 2013;77:2722–7.
[5] Miyazaki S, Taniguchi H, Komatsu Y, Uchiyama T, Kusa S, Nakamura H, Hachiya H, Isobe M, Hirao K, Iesaka Y. Sequential biatrial linear defragmentation approach for persistent atrial fibrillation. Heart Rhythm 2013;10:338–46.
[6] Miyazaki S, Taniguchi H, Kusa S, Uchiyama T, Nakamura H, Hachiya H, Hirao K, Iesaka Y. Impact of atrial fibrillation termination site and termination mode in catheter ablation on arrhythmia recurrence. Circ J 2013;78:78–84.
[7] Miyazaki S, Taniguchi H, Kusa S, Uchiyama T, Hirao K, Iesaka Y. Conduction recovery after electrical isolation of superior vena cava – prevalence and electrophysiological properties. Circ J 2013;77:352–8.
[8] Kato R, Lickfett L, Meininger G, Dickfeld T, Wu R, Juang G, Angkeow P, LaCorte J, Bluemke D, Berger R, Halperin HR, Calkins H. Pulmonary vein anatomy in patients undergoing catheter ablation of atrial fibrillation: lessons learned by the use of magnetic resonance imaging. Circulation 2003;107:2004–10.
[9] Yamane T, Date T, Tokuda M, Aramaki Y, Inada K, Matsuo S, Shibayama K, Miyanaga S, Miyazaki H, Sugimoto K, Sakuma T, Fukuda K, Mochizuki S, Yoshimura M. Prevalence, morphological and electrophysiological characteristics of confluent inferior pulmonary veins in patients with atrial fibrillation. Circ J 2008;72:1285–90.
[10] Hof I, Chilukuri K, Arbab-Zadeh A, Scherr D, Dalal D, Nazarian S, Henrikson C, Spragg D, Berger R, Marine J, Calkins H. Does left atrial volume and pulmonary venous anatomy predict the outcome of catheter ablation of atrial fibrillation? J Cardiovasc Electrophysiol 2009;20:1005–10.
[11] McLellan AJ, Ling LH, Ruggiero D, Wong MC, Walters TE, Nisbet A, Shetty AK, Azzopardi S, Taylor AJ, Morton JB, Kalman JM, Kistler PM. Pulmonary vein isolation: the impact of pulmonary venous anatomy on long-term outcome of catheter ablation for paroxysmal atrial fibrillation. Heart Rhythm 2014;11:549–56.
[12] Sohns C, Sohns JM, Bergau L, Sossalla S, Vollmann D, Lüthje L, Staab W, Dorenkamp M, Harrison JL, O'Neill MD, Lotz J, Zabel M. Pulmonary vein anatomy predicts freedom from atrial fibrillation using remote magnetic navigation for circumferential pulmonary vein ablation. Europace 2013;15:1136–42.
[13] den Uijl DW, Tops LF, Delgado V, Schuijf JD, Kroft LJ, de Roos A, Boersma E, Trines SA, Zeppenfeld K, Schalij MJ, Bax JJ. Effect of pulmonary vein anatomy and left atrial dimensions on outcome of circumferential radiofrequency catheter ablation for atrial fibrillation. Am J Cardiol 2011;107:243–9.
[14] Ejima K, Arai K, Suzuki T, Kato K, Yoshida K, Nuki T, Suzuki F, Uematsu S, Fukushima K, Hoshi H, Manaka T, Ashihara K, Shoda M, Hagiwara N. Long-term outcome and preprocedural predictors of atrial tachyarrhythmia recurrence following pulmonary vein antrum isolation-based catheter ablation in patients with non-paroxysmal atrial fibrillation. J Cardiol 2014;64:57–63.
[15] Fujino T, Takahashi A, Kuwahara T, Takahashi Y, Okubo K, Takigawa M, Ikeda T. Assessment of clinical factors associated with a successful catheter ablation outcome in younger patients with atrial fibrillation. J Cardiol 2014;63:438–43.